Guidelines and reference materials
for promoting integrated soil and nutrient management in
Farmer Field Schools

Reference material for the module on

Tillage

Draft

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Preface

Integrated Soil and Nutrient Management (ISNM) refers to the management of soils, nutrients, water, pastures and crops in a holistic approach, with the aim to improve and sustain crop productivity. It implies practices such as appropriate crop rotations, cover crops, use of manure, crop residues and fertilisers, conservation and no-tillage, moisture management, etc.

In 2000, AGLL published the “Guidelines and reference material on soil and nutrient management and conservation for Farmer Field Schools”[1] (referred as the “Main Guidelines” in this document), based on the successful methodology developed for the promotion of Integrated Pest Management (IPM) in rice. This document has been designed for the Farmer Field Schools (FFS) facilitators, as basic guidelines to be improved and adapted according to the local needs and circumstances.

The present document is an additional training module, which would support on-going projects within the framework of the Soil Fertility Initiative (SFI) and the Special Programme for Food Security (SPFS) with more specific issues concerning “Tillage”.

The aim of this module is not to provide farmers with a comprehensive course on different types of tillage systems, but to assist farmers to adopt improved tillage systems and implements, or to modify their existing systems and implements, so as to be better adapted to the agro-ecological and socio-economic environment, cropping and farming systems.

More specifically the objectives of this module are:

1. to introduce improved tillage systems, with emphasis on zero tillage and conservation tillage, as solutions to identified soil problems (fertility, erosion, water retention, structure, biology),
2. to test by simple experimentation the suitability and potential advantages of zero or conservation tillage, even in situations where farmers are unaware of any disadvantages in their current tillage system.

This document consists of three parts and an annex. The first part presents the main tillage systems, their conditions of applications, their advantages and limitations. The second part shows three examples of exercises focused on tillage practices. The third part presents various tillage implements, with illustrations, advantages and limitations. In the annex, other tillage systems are mentioned and shortly presented. Some pictures illustrate various tillage systems and implements, and modifications are proposed for the implementation of the Farmer Field Schools, following the modules as described in the «Main Guidelines[1]».

Further technical information is also available in various publications (see References).

[1] AGL/MISC/27/2000

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Main tillage systems

The term “tillage” embraces a range of operations applied prior to sowing, to prepare the soil for crop growth. These operations are using various types of implements and machinery to loosen, invert, and mix the soil, modify the surface configuration, change aggregate size, incorporate materials (fertilisers, manure, crop residues, etc.), eradicate weeds, and form openings for seed placement.

The need for and aims of tillage are various and may include:

- the production of favourable conditions for seed germination, seedling emergence, rainwater infiltration, soil moisture retention, root development and growth of tubers;
- the modification of soil aeration and soil temperature;
- the management of weeds, crop residues, pests and diseases;
- the elimination of pastures in crop-pasture rotations;
- the incorporation of fertilisers, green manure and soil amendments.

However, in many situations these objectives can be better achieved through zero tillage or other forms of conservation tillage than through conventional tillage, and usually with the added benefits of savings in cost and labour, together with improvements in soil health over the medium to long term[2]. It is therefore crucial in ISNM courses that attention focuses on whether conventional tillage, or tillage of any kind, is really necessary for the local soils, climate, cropping and farming systems, and farmers’ socio-economic conditions. **Often zero or other forms of conservation tillage will be more beneficial than conventional tillage**, but experiments will often be necessary to find the optimum tillage system.

A description of a tillage system will include details of the types of machinery and tillage implements used for each crop in the rotation, the specifications, settings, working velocity, depth of operation, number of passes, timing and sequence of the different tillage operations, together with details of the seeding and stubble management machinery employed.

Classification

A very large number of different tillage systems and implements, powered by tractors, animals and by hand, are in use in different parts of the world. To facilitate the discussion of tillage systems, they have been classified into three categories (see below for details): “**conventional tillage**” signifying a high degree of soil disturbance, “**reduced tillage**” in which one or more of the conventional tillage operations are eliminated, and “**conservation tillage**” in which there is minimal soil disturbance and crop residues are, if at all possible, left on the surface to protect and benefit the soil. The term “minimum tillage” is not used to avoid confusion which arises from the many different meanings of this term as used in different parts of the world.

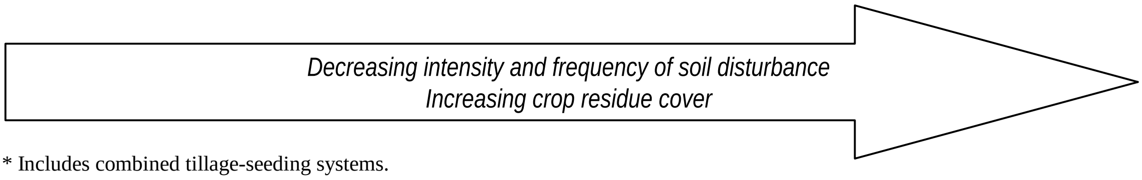
In particular, **conservation tillage** normally refers to tillage systems that do not invert the soil, which retain crop residues on the surface, and which optimise soil and water conservation. It has been defined as “any tillage or planting system in which at least 30 % of the soil surface is covered by plant residue after planting to reduce erosion by water; or where soil erosion by wind is the primary concern, with at least 1 t/ha of flat small grain residue on the surface during the critical wind erosion period” (CTIC, 1993). Conservation tillage is thus a broad term which

[2] Soil health refers to the productivity of a soil as influenced by management practices; the concept of soil health being considered as comparable to the health of a person.

includes zero tillage, strip tillage, tine tillage and ridge tillage.

Figure 1: Tillage systems classified according to the degree of disturbance to the soil and the surface cover of residues

Conventional tillage		Non-Conservation Tillage	Conservation tillage				
Mouldboard plough	Disc plough	Reduced tillage	Ridge Tillage	Reduced* Tillage	Tine Tillage	Strip Tillage	Zero Tillage



* Includes combined tillage-seeding systems.

Source:FAO-IITA, 2000

The extension of land under conventional tillage is diminishing globally because of the very evident advantages of conservation tillage systems in many areas, and the progressive development of suitable conservation tillage machinery and implements for tractor-powered and animal traction systems. Improved planters for manual conservation tillage systems have also been developed.

The power sources for the various tillage systems may be wholly tractor, animal, or manual, or a combination of these for different field operations (see chapter on Tillage implements). For example, primary tillage may be using a tractor, and secondary tillage, planting and weeding by hand or animal traction.

However soil with a fine structure is much more susceptible to crust formation and erosion by rainwater (**Table 1**) and so shouldn't be left bare. Therefore, systems using crop residue cover and cover crops may be preferred.

Table 1. Effects of tillage on runoff and soil loss for soils cultivated with Maize in Nigeria

Slope %	Bare tilled soil		Ploughed		Zero tillage	
	Runoff %	Erosion (mg/ha)	Runoff %	Erosion (mg/ha)	Runoff %	Erosion (mg/ha)
1	18.8	0.2	8.3	0.04	1.2	0.001
5	20.2	3.6	8.8	2.16	1.8	0.001
10	17.5	12.5	9.2	0.39	2.1	0.005
15	21.5	16.0	13.3	3.92	2.2	0.002

Source: Rockwood and Lal, 1974

In the following, the three main tillage systems are described, with focus on the conditions of application, the advantages and limitation. A fourth one has been added as it may be of major importance in some cases, before applying conservation tillage for example: the subsoiling.

Zero tillage

Zero tillage refers to direct planting into the residues and stubble of a previous crop (**Picture 1** in annex 2), or the mulch of a cover crop or fallow, without any previous tillage or soil disturbance, except that which is necessary to place the seed in the soil. In zero tillage systems, weed control relies on the use of herbicides and rotations practices. Nevertheless, if zero tillage is only used for some crops of the rotation, while tillage is still practised for others on the same plot, the tillage system can't be considered as a conservation tillage system.

Synonyms: direct drilling / no till / direct seeding / direct seedling

Variations: mulch tillage (see **Annex 1**).

Context of application

The areas under zero tillage and the range of conditions under which it can be successfully practised are continually increasing as more experience is gained with this system. It is suited to manual and mechanised systems. Nevertheless, *zero tillage* is most suited to the following conditions:

- Subhumid and humid climates (experiences are ongoing under other conditions)
- Soils which are very susceptible to erosion, surface sealing and crusting
- Soils with low water holding capacities, and those subject to periodic droughts
- Soils with excessively high temperatures during seed germination

In general, it is preferable to eliminate or substantially reduce the limitations imposed by severe nutritional deficiencies, very compact layers, poor drainage, serious weed infestations and widespread micro-topographical irregularities prior to initiating zero tillage. However, recent evidence from Brazil has shown that under certain conditions it is possible to overcome the effects of nutrient deficiencies, compacted layers and weed infestations by sowing a cover crop prior to starting zero tillage. If these limitations cannot be largely overcome, it would be advisable to apply another type of conservation tillage, at least as a first step.

For newly cleared land, and if mechanised systems are to be used, tree roots have to be removed from the topsoil to avoid damage to no-till drills and planters.

It is recommended to begin zero tillage with an initial residue cover of at least 80%. If there is a lack of residues, mulch tillage is recommended in which a cover crop is sown prior to initiating zero tillage, or as part of the rotation. Alternatively, the first two or three crops sown to zero tillage should be crops that produce large quantities of biomass, which decompose slowly.

The **crop rotation** is one of the important factors affecting the success or failure of zero tillage systems. Other major problems that may arise are:

⇨ Difficulties to produce and maintain enough residues on the soil surface (competition with livestock, use as energy source, degradation by termites, decomposition, traditional burning...)

⇨ Lack of oxygen due to soil waterlogging

⇨

⇨ Difficulties to acquire no-till drills or planters for animal traction or tractor-powered systems

However, these factors should not be considered so insuperable that it becomes impossible to successfully introduce zero tillage. Encourage discussions to try and identify alternative strategies that will surmount these problems, and allow sufficient residues to be left in the field.

Box 1. Examples of strategies to save or produce enough crop residues for covering the soil

- Produce alternative sources of fodder, such as silage or hay from improved pastures, fodder trees, etc.
- Introduce a cover crop as part of the rotation in order to increase biomass production.
- Introduce stall-feeding.
- Introduce fencing and controlled grazing to control the amount of residues left in the field.
- Modify the crop rotation so that more crops producing a high biomass (e.g. forage sorghum, maize or a vigorous cover crop), crops with more slowly decomposable residues (e.g. *Crotalaria juncea*), or cover crops that control termites (e.g. *Canavalia ensiformis)* are introduced to compensate for the rapid decomposition of residues or their consumption by termites.

In Brazil, zero tillage has recently been successfully introduced in situations that were previously considered to be unsuitable for zero tillage:

- In semi-arid areas by using a cover crop mixture of pigeon pea (*Cajanus cajan*) and forage sorghum (*Sorghum bicolor*) prior to commencing zero tillage,

- In very degraded compact soils using a cover crop of radish (*Raphanus sativus*) as a "biological subsoiler" prior to initiating zero tillage,
- With horticultural crops by sowing into a cover crop mixture of black oats (*Avena strigosa*), radish (*Raphanus sativus*) and common vetch (*Vicia sativa*).

Implementation

Crop residues are shopped and spread during or after the harvest, using a rotary mower, straw chopper, or by manual slashing.

Weeds are controlled through the use of herbicides and appropriate crop rotations. Any weeds that germinate between the harvest of the previous crop and the beginning of zero tillage should be periodically slashed or mown to avoid seed set. The first few zero tillage crops should preferably allow easy control of broad leaf and graminaceous weeds. After 2 or 3 years, the amount of herbicides needed decreases a lot. Appropriate management of rotations (including cover crops) should then largely control weeds without the need for herbicides.

Seeding is carried out using no-till drills and no-till planters, preferably equipped with fertiliser hoppers for basal fertiliser application in mechanised systems (See chapter on Implements). Before sowing, check that the depth of penetration of the front coulter is 1 to 3 cm deeper than the planned sowing depth. Check also that the seed rate and depth of seeding are appropriate. If not, adjust the feed mechanism and the depth of the double disc coulter. Check that soil moisture is suitable for sowing; in soils that are too wet, the seed will not be adequately covered by soil and the seed slot will not be closed by the press wheels.

Advantages and limitations

Advantages	Limitations
➠ Better yields and good economic returns ➠ Risks of soil erosion reduced ➠ Better rainfall infiltration and soil moisture, less evaporation ➠ High temperatures and temperature variations reduced in the seed zone, less frequent and severe short (10-15 day) droughts ➠ Better germination and crop establishment in areas with supra-optimal soil temperatures ➠ Stimulation of soil biological activity, macro-porosity and biopore formation, increases soil organic matter content and improves structure ➠ Fuel consumption and risks of compaction reduced by about 40-50% because of the limited number of operations ➠ Less machines, lower maintenance costs ➠ Time and labour reduced by up to 50-60%, which is especially advantageous for timely sowing at the onset of the rains and may increase the number of crops grown per year ➠ Crop diversification due to necessary rotations	➠ Permanent soil cover required (cover crops, residues, mulch, fallow, etc) ➠ Not suited to poorly drained soils, with the possible exception of irrigated rice, ➠ Prior improvement needed in case of severe nutritional deficiencies, very compact layers, or weed infestation[3] ➠ More difficult initially on soils which are highly susceptible to compaction or hardsetting[3] ➠ More difficult initially on some massive clayey soils[3]

[3] these difficulties are not necessarily insurmountable if a vigorous cover crop or fallow can be established prior to intiating zero tillage, and a suitable crop rotation is employed.

Reduced / conservation tillage

Reduced tillage refers to systems in which the whole surface is tilled, but one or more operations that would normally be implemented in conventional tillage are eliminated. This definition is broad, and therefore includes many systems varying in the type of implements, and the frequency and intensity of tillage. Consequently very few surface residues may be left in some systems, but more than a 30% cover may remain in other systems. Some reduced tillage systems are therefore classed as conservation tillage whilst others are not.

In general, reduced tillage systems do not use either mouldboard or disc ploughs.

Reduced tillage includes systems in which land preparation and seeding are separate operations, as well as those in which they are combined into a single operation. Within the first category, one or maximum two passes with chisel plough, disc harrow or rotary cultivator (see chapter on Tillage implements) are followed by seeding. The following information deal with combined tillage-seeding systems, which are more suited to ISNM. These systems include strip tillage-seeding, ridge tillage-seeding and deep tillage-seeding, or rip-plant.

Context of application

Strip tillage-seeding is particularly suited to:

- Soils with moisture deficits
- Erosion- and crusting-susceptible soils

Deep tillage-seeding (Fig. 2) is particularly suited to:

- Hardsetting soils and very compacted soils
- Erosion- and crusting-susceptible soils
- Soils with moisture deficits

Ridge tillage-seeding, including *raised beds* and *mounds* (description and **Pictures 2 & 3** in annex), is particularly suited to:

- Imperfectly drained soils
- Tuber crops

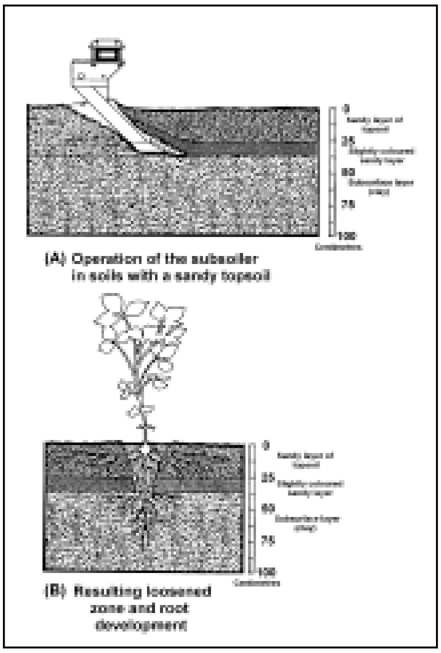


Figure 2: Subsoiling and seeding in one operation

Implementation

Combined tillage-seeding systems require special machinery consisting of various components that combine land preparation and seeding into one operation. There are many variations in the types of machinery used with tractors or animal traction, but they tend to be very large because of the space needed by the individual components, and between the individual components, tines and discs to avoid clogging by residues.

Advantages and limitations

The three systems mentioned above have the same advantages and limitations as those of the corresponding tillage systems (see Deep tillage below and Strip and Ridge tillage in annex) in which tillage and seeding are separated, but with the following additional properties:

Advantages	Limitations
➠ fuel consumption, risks of compaction, repair and maintenance costs reduced ➠ Time and labour requirements reduced	➠ Specialised nature, limited availability and high cost of the implements

Conventional tillage

Conventional tillage (**Picture 4**, annex 2) refers to tillage with a high degree of soil disturbance that involves mixing of the surface layers, with the aim of controlling weeds and preparing a seedbed suitable for germination. The two principal variations, mouldboard ploughing and disc ploughing, are based on the nature of the primary tillage operation. The mouldboard plough inverts the soil, whereas the disc plough turns the soil without inversion.

Context of application

Soil inversion is the most drastic operation carried out on the soil. Therefore, it should be applied only if there is no alternative, and preferably not every year.

Due to the number of operations and consequences of c*onventional tillage* practices, this tillage system may be applied in restricted situations, and for a short time:

- In crop-pasture rotations for the incorporation of the pastures.
- When weeds can only be effectively controlled by mechanical means, e.g. by burial, on poorly drained soils, when herbicide costs are high, or are rejected for ecological reasons.
- When lime or other soil amendments like manure, rock phosphate or P-fertilizer need to be incorporated deeply (only necessary every few years).
- For the recuperation of degraded soils which involves breaking up dense or indurate soil layers, when the preferred subsoilers or paraplows are not available. This will probably only be necessary at the onset of the reclamation process, and may not even be necessary if a “biological subsoiler” type of cover crop can be established followed by zero tillage.

Conventional tillage should be abandoned to more conservation practices, especially in the following situations:

- When soils are very susceptible to compaction and/or hardsetting: if it is not economically feasible to recuperate the soils through planted or natural fallow or rotations with cover crops, strip and tine tillage would be preferable to conventional tillage.
- For pest and disease control, rotations and treatment can be combined with more conservation tillage systems with efficiency, economic and environmental benefits.

Conventional tillage should not be applied:

- On soils which are susceptible to: crusting, compaction, water and wind erosion; risks of compaction are particularly high when the soil surface is dry but the moisture content at 20 cm depth is high.
- In desertic and semi-desertic areas, as conventional tillage maximise soil water evaporation and pulverisation (risks of wind erosion). Conservation or no-tillage practices must then be applied, with alternative strategies to increase residue cover on soils.
- If the subsoil’s physical and chemical characteristics are unfavourable, as soil inversion can adversely affect germination and initial plant growth.

Implementation

Conventional tillage consists in a succession of tillage operation, usually called “*Primary*” and “*Secondary*” tillage. The main objective of primary tillage is weed control and residue burial, and that of secondary tillage is to prepare a firm seedbed conducive to good germination.

Primary tillage requires the greatest power. It is generally implemented to invert the top layer of soil and incorporate weeds and crop residues. Usual implements used are mouldboard or disc plough in mechanised systems, mouldboard or wedge-shaped plough in animal traction systems (See chapter on Implements).

Secondary tillage involves diminution of aggregate size, levelling and compaction of the soil, if necessary. The number of passes and the type of implements used will depend on soil texture and moisture content.

Seeding and basal fertiliser application are often separated, which increases compaction, fuel, time consumption and costs, but combined implements may be used:

- ⇨ A conventional seed-drill or planter, preferably with a fertiliser hopper, may be used to place the seed and fertiliser, and should be equipped with press-wheels to cover the seed and firm the seed-soil contact rather than chains.
- ⇨ For animal traction seeding, a conventional planter with a combined fertiliser hopper can be used, or furrows can be opened using a cultivator or ridger, and the seeds dropped in manually.
- ⇨ For manual tillage, planting is most efficiently carried out using a jab planter. Alternatively, seeds can be dropped into holes made with a planting stick, rotating spike (**Picture 5**, annex 2), or into furrows formed with a furrow-opener.

Advantages and limitations

Conventional tillage has many negative features mainly because of the excessive degree of soil disturbance, the lack of a protective residue cover on the surface to protect the soil from erosion, runoff and evaporation, and in the case of mechanised systems, high operational and maintenance costs.

Advantages	Limitations
➠ Mechanical control of weeds, diseases and pests by burying crop residues ➠ Incorporation of pastures in crop-pasture rotations ➠ Incorporation of fertiliser, manure, pesticides, pre-seeding herbicides and green manure, and deep incorporation of lime ➠ Deep ploughing can break up shallow compacted layers to encourage root development, but this is better accomplished by deep or tine tillage	➠ Higher risks of crusting, erosion, and loss of water by evaporation because the soil is left bare ➠ Higher risks of compaction, and ploughing every year at the same depth forms a compacted layer at the base of the plough and causes the blockage of soil pores which hinders drainage ➠ High losses of soil moisture due to the numerous tillage passes ➠ Inhibition of soil biological activity due to the high degree of soil disturbance and the lack of residues on the surface ➠ Much equipment required ➠ High fuel consumption ➠ Very time consuming, which can be detrimental in areas where timeliness of sowing is essential to achieve acceptable yields

Subsoiling

Subsoiling is a form of tine tillage in which heavy tined implements are used to break up dense, compacted, or indurate layers in the subsoil, without inverting it. Therefore it improves root penetration and infiltration rate, which can be helpful for soils with drainage problems as well as those with moisture deficits.

Context of application

Deep tillage or subsoiling is a **soil recuperation practice** that is only used when it is necessary to break up dense or indurate subsoil layers at a greater depth than usual tillage practices (up to 50cm with 100 hp tractor).

Deep tillage may also be used to increase the oxygen supply to the roots of crops in soils with dense impermeable subsoil causing perched water tables in wet periods. Loosening the dense layers will encourage deeper rainwater percolation allowing oxygen into the rooting zone.

Due to the high energy demand, this tillage practice is only available for mechanical-powered systems. It may not be applied every year. In contrast, the more usual tine tillage is a conservation tillage practice used to prepare soils each season (see **Annex 1**).

Implementation

Subsoiling should only be carried out when the soil is dry or slightly moist.

Usual implements are rippers, subsoilers, or paraplows (see chapter on Implements). To avoid residues clogging the implements, residues and weeds should be well chopped and uniformly spread over the plot, by using a rotary mower or straw chopper, or by slashing.

For mechanised harvests the combine harvester should be equipped with a straw chopper and spreader.

Subsoilers can be combined with seeding systems like ripper-planter or ripper-bedder.

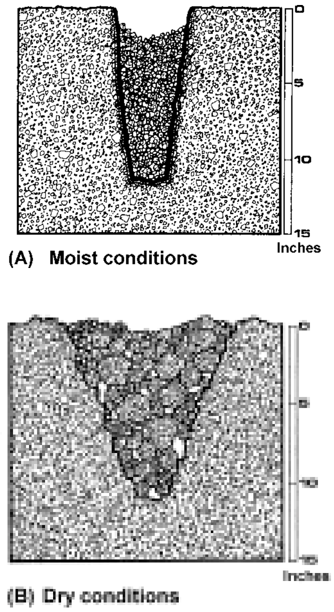


Figure 3: Subsoiling under moist and dry conditions

Advantages and limitations

Advantages	Limitations
➠ Only way to break up dense or indurate subsoil layers at a greater depth than usual tillage practices ➠ No inversion of the top soil ➠ Better root penetration and water infiltration	➠ High time and energy consumption ➠ Specific implements (mechanised) ➠ High costs ➠ Under moist conditions, may create channels without loosening the profile (**Fig. 3A**) ➠ Under too dry conditions, may leave large aggregates (**Fig. 3B**.), creating unfavourable conditions for germination and inducing the necessity for a secondary tillage, which may lead to compaction if rain falls between the two operations ➠ Not applicable every year ➠ Only suitable to mechanised traction

Implementation of the Farmer Field Schools with focus on tillage

The tillage module should follow the general document "Guidelines and reference materials for on integrated soil nutrient management and conservation for Farmer Field Schools"[4], as referred to as "**Main Guidelines**", with some modifications or additional topics as indicated in the chapter about «Exercises and trials», and below.

Inventory of farming systems

In addition to the information already required, details of the tillage systems and implements employed should be provided by farmers, for each crop and pasture identified in the area. The crops should be listed in the same sequence in which they are sown in the rotation; thus some crops may be listed more than once if they form part of two or more different rotations.

Field identification of soil and nutrient problems

This session may present problems that can best be overcome by changing or modifying existing tillage practices or implements.

Box 2. Soil problems commonly overcome by tillage practices

- **Inadequate water supply and availability** - overcome by breaking up surface crusts to aid infiltration, breaking up root-inhibiting subsoil layers to extend the rooting zone, constructing ridges and basins to retain runoff, and leaving residues on the surface to reduce evaporation and improve infiltration.
- **Inadequate oxygen supply** - overcome by breaking up impermeable subsoil layers to enhance oxygen diffusion into the subsoil, constructing graded channels to drain off excess water, and by constructing ridges, raised beds and mounds to elevate the rooting zone above the water table.
- **Low soil fertility and site instability due to water or wind erosion** - overcome by conservation tillage which leaves a protective layer of crop residues on the soil surface, and by constructing ridges and furrows to reduce wind velocity and retard runoff.
- **Poor seed germination** - overcome by diminishing aggregate size, by breaking up impermeable subsoil layers to enhance oxygen diffusion, and by constructing ridges and beds to elevate the germination zone above the water table.
- **Low seedling emergence** - overcome by breaking up surface crusts, and by leaving crop residues on the surface as a protection against crusting from raindrop impacts.
- **Low productivity due to weed, disease and pest infestations** - overcome by uprooting weeds and leaving them on the soil surface, and by burying weeds and infected crop residues.
- **Poor tuber growth** - overcome by loosening dense layers.
- **High production costs due to high labour, machinery or maintenance costs** - overcome by practising zero tillage, combined tillage-seeding or reduced tillage systems.

Identifying the causes

These should reveal the limiting causal factors and whether tillage might be a possible solution to the problems previously identified.

[4] AGL/MISC/27/2000, FAO, 2000.

Identification of possible solutions

A list of problems and their causes for which specific tillage may be a solution, and suggested tillage practices and implements to overcome the problems are presented **Table 2**. The purpose of this table is to provide facilitators with suggestions; it is not an exhaustive list, nor are the possible tillage solutions listed necessarily the most appropriate for all situations. The preferred zero and mulch tillage solutions are given in bold and with a grey background.

Table 2. Soil and nutrient problems, their causes and possible tillage solutions / management practises

Problem	Cause	Possible tillage solution & management practises
Low soil fertility and productivity	▪ Low organic matter content and poor topsoil structure	**Zero, or mulch tillage** to allow the use of crop residues, leguminous cover crops or fallow as source of nutrients
		Mouldboard and disc ploughs, disc harrows and hoes to incorporate, green manure, compost, etc
	▪ Low nutrient retention capacity	**Zero or mulch tillage** and **leave crop residues on the soil** to minimise losses of soil organic matter and nutrients
	▪ Erosion of topsoil	**Zero, mulch, strip or tine tillage and keep the soil cover**
		Ridge tillage to impede run-off
		Contour and strip tillage and sowing
		Cultivators and hoes to break up surface crusts
		Tillage at the end of the rains
	▪ Weeds	Disc harrows, sweeps, rod-weeders and cultivators or hoes to incorporate weeds
		Mulch tillage with cover crop to suppress weeds
	▪ Pests or diseases	Mouldboard or disc plough, harrows or hoes to incorporate crop residues
Presence of toxic substances	▪ Aluminium or manganese	Disc harrow, disc or mouldboard plough to incorporate lime, manure etc.
	▪ Sodium	Disc harrow, disc or mouldboard plough to incorporate gypsum
Insufficient supply and retention of water	▪ Low infiltration	**Zero, mulch, strip or tine tillage and keep the soil cover**
		Deep till with subsoiler, ripper, paraplow or double digging to loosen impermeable subsoil
		Lister plough or disc ridger to create furrows and ridges or tied ridges to retain water
		Hoe to form pits or half moons for retaining water
		Tine tillage with chisels or cultivators, or hoes to break up surface crusts
	▪ High evaporation / transpiration	**Zero tillage and maintain crop residues at the surface**
	▪ Low organic matter content	Disc or mouldboard plough or hoe to incorporate manure or cover crops
		Mulch tillage
	▪ Restricted rooting	Deep tillage with subsoilers, rippers or paraplows to loosen dense subsoil layers
		Zero/mulch tillage using "biological subsoiler" cover crops
		Disc or mouldboard plough to incorporate lime, gypsum, fertilisers etc to overcome toxic substances and correct nutrient deficiencies
Insufficient oxygen supply	▪ High water table or impermeable layers	Disc or mouldboard plough or hoe to form raised beds, cambered beds or mounds
		Lister plough or disc ridger to create ridges and graded furrows
		Mulch tillage using a "biological subsoiler" cover crop to break up impermeable layers

		Deep tillage with subsoilers, rippers and paraplows to loosen dense subsoil layers
Low biological activity	▪ Lack of residues, soil organic matter and active soil biota	**Zero tillage to maximise residue cover**
		Mulch tillage with cover crops
		Disc or mouldboard plough to incorporate pastures
		Mulch tillage with cover crop or natural fallow
	▪ Toxic pesticides and herbicides	*See Cause: [Weeds] and [Pests or diseases]*
Site instability	▪ Water erosion caused by runoff	**Zero tillage to maximise residue cover**
		Disc or mouldboard ploughs to construct earth bunds
		Lister plough or disc ridger to create ridges or tied furrows
	▪ Wind erosion	**Zero or mulch tillage to maximise residue cover**
		Lister plough or disc ridger to create ridges and furrows
Restricted root or tuber growth	▪ Dense layers	Deep tillage with subsoilers, paraplows, rippers or chisel ploughs to break up dense layers
		Mulch tillage using a biological subsoiler cover crop to break up dense layer
	▪ Lack of oxygen	*See Problem: [Insufficient oxygen supply]*
	▪ Lack of phosphorus	Hoes or disc harrows to incorporate phosphate fertilisers, rock P, lime
	▪ Toxic substances	*See Problem: [Presence of toxic substances]*
Poor seed germination	▪ Lack of moisture	**Zero tillage to leave residues on surface**
	▪ Lack of oxygen	*See Problem: [Insufficient oxygen supply]*
	▪ Excessively high temperatures	**Zero tillage and leave residues on the surface** to protect the soil
	▪ Very low temperatures	Lister plough or disc ridger to create ridges and furrows
		Disc or mouldboard plough to form raised or cambered beds, and to incorporate residues
	▪ Cloddy structure	Strip tillage with cultivators and rakes
		Disc harrow to reduce clod size or incorporate organic matter
		Mouldboard plough to incorporate pasture grasses
		Mulch tillage with fibrous-rooted cover crop
Poor emergence	▪ Crusting	**Zero tillage and leave residues on the surface** to protect the soil from splash erosion and improve soil structure
		Disc harrows to incorporate organic manure
		Lister plough or disc ridger to create ridges for planting
	▪ Dense topsoil	Tine tillage (chisel plough) to reduce soil strength
		Disc harrows to incorporate organic manure
		Disc or mouldboard ploughs to incorporate cover crops
		Mulch tillage with fibrous-rooted cover crop
High production costs	▪ High labour costs	**Zero tillage**
		Reduced tillage
		Combined tillage & seeding operations
	▪ High machinery costs	**Manual zero tillage**
		Animal traction tillage
	▪ High pesticide costs	Disc harrow, sweeps, cultivators to control weeds
		Mulch tillage with cover crop to control weeds
		Disc harrows to incorporate residues
Environmental problems	▪ Toxic pesticides and herbicides	*See Cause: [Weeds] and [Pests or diseases]*
	▪ Sediment contamination	**Zero tillage, conservation tillage** and SWC practices to avoid runoff, soil erosion and contamination of water

Selection of possible solutions for testing by farmers

The farmer needs to select one of the possible solutions for testing, which should be the most appropriate one for his/her particular circumstances. These decisions are best arrived at through participatory focussed discussions.

Table 2 shows that for the majority of problems and causes, zero or mulch tillage are possible solutions. This is generally true for tractor-powered, animal traction and manual tillage systems. In fact, zero tillage may be an appropriate solution to many contrasting types of problems and causes in a wide range of agro-ecological and socio-economic farming conditions.

Moreover, in addition to the possibility of overcoming commonly identified problems, **zero and mulch tillage generally confer important additional benefits, such as savings in operational and machinery maintenance costs, and reduced labour**. Other medium to long term benefits may be reductions in the severity of environmental problems and improvements to soil health.

It is therefore recommended that emphasis should be given to zero or mulch tillage when selecting the tillage treatment to be tested, unless it is clear that other tillage practices would be more appropriate.

Visits to observe practices implemented in other areas

This may be a useful opportunity for introducing zero and other conservation tillage systems to farmers who are unfamiliar with them, and may help convince farmers to test one of these new systems and to compare it with their existing tillage system.

Design and layout of the tests

The size of the plots will vary depending on whether tillage is carried out with tractors, animal traction or is manual. For tillage tests with tractors, test plots should be at least 20 meters wide and 50 meters long in the direction of tillage, so that the tractor can attain sufficient velocity for the implement to work at its optimum efficiency over a minimum run of 30 meters. When fuel consumption and work rates are important, plot size should equal the length of the field and be at least 40 meters wide to permit a realistic estimation of these variables. For animal traction tillage tests, plot sizes may be smaller with minimum dimensions of 30 meters length and 15 meters width, whereas for manual tillage tests, plot sizes can be reduced to 100-200 m^2 in size.

The design of the test is usually very simple involving just two plots, the "treated" plot where the new tillage treatment is to be applied, and the "control" plot representing the farmer's normal tillage practice against which the new tillage treatment, preferably zero or mulch tillage, will be compared.

The number of replications is normally restricted to one per farm, i.e. one "treated" plot and one "control" plot, the latter plot often located adjacent to the former, provided soil types, management and cropping histories are the same. It is always desirable to repeat the same tillage test on several farms to assess the general applicability of the tillage treatment to the area.

Implementation and monitoring of the tests

See chapter on Exercises and trials in the «Main Guidelines» and the examples of possible exercises and trials at the end of this chapter.

Evaluation of tests

The evaluation occurs at the conclusion of the test, which may preferably be after three years or more, and assesses whether the tillage treatment has satisfactorily overcome the identified problems from technical, social, economic and environmental standpoints as follows:

Technical evaluation: the effect of the tillage treatment should be evaluated in terms of the extent to which it has reduced the severity of the identified problem (e.g. erosion, moisture deficit, weed infestation), and the extent to which it has improved crop yield or yield reliability.

Social evaluation: The most important social factors to be evaluated are the extent to which the tillage treatment has reduced physical exertion and drudgery, has reduced the number of man-hours of labour, and the consequent extent to which other beneficial activities can be undertaken. When animal traction is introduced, the added benefits, obligations and constraints of looking after traction animals must be considered. Suitable indicators to permit a social evaluation will need to be identified through discussions with the participating farmers.

Economic evaluation: the economic benefits are assessed by comparing the profit (gross margin) achieved by the tillage treatment (treated plot) with that obtained from the farmer's normal tillage practice (control plot). The gross margin is calculated from the difference between the income obtained from the sale of the produce and the variable costs of production, i.e. labour, seed, fertiliser, pesticides, transport etc (see **"Main Guidelines",** Table 1, Annex 5). For animal traction systems the costs of maintaining the animals needs to be taken into account. It is important that all data are obtained from plots sufficiently large that they are representative of field-scale conditions.

The economic evaluation must also consider the capital costs of introducing new tillage systems/implements. For example, the cost of animals, harness, implements and housing for animal traction systems, and the cost of purchasing direct drills and planters, and possibly mowers when introducing zero tillage. For the satisfactory implementation of zero tillage systems, an appropriate crop rotation is essential which invariably consists of both narrow and widely spaced crops, and so both direct drills and planters will often be required.

Environmental evaluation: the main environmental factors to be evaluated in tillage tests of a year's duration, using subjective ratings identified during participatory discussions, are:

- The extent to which toxic chemicals are used. It is important to try and keep abreast of recent developments in the toxicity status of agrochemicals, as the status can change as new research data appears.
- Water and wind erosion of farmland.
- Atmospheric pollution, for example, from burning crop residues.

Environmental factors to be evaluated over longer periods of 3 or more years are:

- Water supplies - water levels in rivers and ground waters as revealed by the levels in wells and the persistence of springs. Qualitative subjective ratings may be used.
- Water quality - sediment content and pesticide concentrations. Where laboratory facilities are not available, the colour, taste and smell are often good indictors
- Soil health; this is most easily evaluated by farmers and facilitators using a multi-factor questionnaire which assesses whether various positive or beneficial features and practices have increased, decreased or not changed, and whether various negative features and processes have increased, decreased or not changed during the 3 or more years since the beginning of the tillage test (see **"Main Guidelines",** Table 2, Annex 5).

Examples of possible exercises and trials

The procedures used in implementing the tests will vary with the type of tillage system / implements being tested, and depending on whether tractor, animal traction or manual power is used. Since many of the changes to soil characteristics, weed, disease and pest problems induced by a change of tillage practice become apparent only slowly, **exercises and monitoring should preferably last, at least, two or three years**.

Monitoring of the tests should occur periodically during the implementation. The choice of indicators for monitoring changes in soil, crop conditions and crop yield will depend on the objectives of the test, i.e. on the nature of the problem(s) to be overcome. The indicators must also be sensitive enough over the growing season or the duration of the test, to reflect changes in the limiting factors that the possible solution was intended to overcome.

Table 3 presents possible indicators for various technical problems. Some of these, such as those for soil biological activity, are likely to show noticeable changes only over the medium to long term, whereas other, such as those for wind erosion, may be apparent only in occasional years. Most of the indicators can be assessed quantitatively, but some can only be assessed qualitatively using a subjective rating classification. The indicators need to be assessed simultaneously for both “treated” and “control” plots for the comparisons to be valid and meaningful.

Table 3. Indicators for monitoring technical changes in tillage tests.

Problem	Indicators
Soil fertility	Crop foliar deficiency symptoms, foliage colour, crop growth/yield (see below), weed diversity, weed density, weed species.
Crop growth/yield	Crop height, vigour, number of tillers, leaves, cobs, length of panicles, yield.
Disease incidence	Development of disease symptoms.
Pest incidence	Numbers of pests, degree of pest attack.
Weed infestation	Numbers and biomass of noxious weeds.
Toxic substances	Soil analysis, crop growth/yield (see above).
Water supply	Soil moisture by feel and colour, surface residue cover, surface crusting or sealing, surface porosity, crop wilting, rooting depth.
Oxygen supply	Depth to water table, soil moisture content by feel and colour, rooting depth, weed species that love water, e.g. *Cyperacea.*
Biological activity	Numbers of worms and other organisms, casts, burrows, termite galleries, biopores, quantity and persistence of surface residues.
Water erosion (site stability)	Density and size of rills, soil pedestals, root exposures, accumulations of transported soil particles, splashed soil particles.
Wind erosion (site stability)	Size and number of sand deposits, micro-dunes, plant root exposures, crop inclination.
Root restriction (excessive soil strength)	Root depth, root pattern, soil consistency, soil resistance to a spade, density of visible pores.
Tuber development (excessive soil strength)	Soil consistency, soil resistance to a spade, number, size and weight of tubers.
Seed germination	Percentage seed germination
Seedling emergence (excessive soil strength)	Percentage seedling emergence, thickness and strength of soil crust.

The following pages provide some examples of the type of discovery-based exercises and trials that could be undertaken by farmers. Other exercises and trials may be more appropriate and thus should be developed within the local Farmer Field School framework.

Example 1. Zero tillage to reduce erosion, and to increase soil moisture, soil biological activity and crop yields.

This example[5] may be the recommended tillage treatment for many situations, and can apply to tractor-powered, animal traction and manual tillage systems.

Material required: machinery, equipment and supplies for land preparation, seeding, weeding, harvesting and the application of fertiliser, manure, herbicides and pesticides. Stakes, crop residues, spring balance, notebook.

The example given is for an area with 2 crops per year, maize followed by beans.

Procedure:

1. Select a field of maize ready for harvest on gently sloping land, where the soil is typical of the area, is susceptible to soil losses by erosion, moisture losses by runoff and evaporation, has low biological activity and a low productivity.

2. Mark out with stakes two plots, either adjacent or close together, which are orientated parallel to the direction of maximum slope, extend down the whole length of the field, and are not less than 20 meters wide.

3. Harvest the maize following normal farmer practice. If this involves removing all crop residues, follow this practice for the control plot but leave all crop residues on the treated plot.

4. Prepare the land in the control plot according to normal farmer practice. Leave the treated plot undisturbed with a good residue cover, flatten the stubble with a roller-cutter, and apply a burn-down pre-sowing herbicide such as glyphosate to control weeds.

5. Sow the whole field with beans.

6. Control weeds following normal farmer practice for the treated plot, and apply herbicides to the treated plot. All subsequent management practices, such as fertilisation, manuring, and pesticide applications, should be the same for both the treated and control plots.

Monitoring:

7. At periodic intervals of 2-4 weeks during the growing season, and especially during periods of drought and shortly after heavy rains, compare the treated and control areas by making several observations for each of the following soil and crop indicators:

- ⇨ crop appearance (foliage colour and degree of plant wilting),
- ⇨ evidence of soil erosion and runoff (rills, soil pedestals capped by stones, exposed roots),
- ⇨ biological activity (presence of soil organisms, earthworm casts)
- ⇨ soil moisture in the topsoil and subsoil (by feel and soil colour).

Evaluation:

8. Harvest the treated and control plots separately, and record the yields.

9. Calculate the gross margins of the treated and control plots.

10. Evaluate the effect of zero tillage by comparing the indicators of erosion, soil moisture, biological activity, crop yields and profit (gross margin) for the treated and control plots.

Note: the test should continue for a minimum of three years if possible, and a second final evaluation carried out after three years.

Discussion: Initiate a discussion on the advantages (e.g. reduced erosion, less drought stress, greater biological activity, higher yields and greater profit ?), disadvantages (e.g. cost of no-till seed drills, loss of crop residues for fodder ?), and feasibility (possibility of producing additional fodder to compensate for leaving crop residues in the field, possibility of adapting existing drills for zero tillage ?). Discuss for which soil types, crops and farming systems the practice would be most appropriate in the area.

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[5] Adapted from the "**Main Guidelines**", Trial 1, page 68.

Example 2[6]. Deep tillage to encourage deeper rooting, increased soil water availability and higher yields.

Material required: Tractor with subsoiler or paraplow, machinery, equipment and inputs for land preparation, seeding, weeding, harvesting and the application of fertiliser, manure, herbicides and pesticides, stakes, spring balance, paper and markers. The tillage systems may be manual, tractor-powered or by animal traction.

Procedure:

1. Select a field where problems of restricted water availability due to dense subsoil layers impeding root penetration are known to occur. The soil should be representative of the soils in the area in terms of morphology, cropping and management history.

2. Confirm the presence of these dense root-restricting subsoil layers by digging 2-3 pits in the field. Examine the soil profiles and determine the depth to the upper and lower boundaries of the dense root-restricting layer.

3. Decide which crop is to be sown; it should be a crop that is sensitive to moisture stress and which responds well to deep tillage.

4. Select and mark out with stakes two plots - treated and control plots, each of which is not less than 50 m long in the direction of tillage and 20 m wide, and which are representative of the whole field in terms of soil characteristics, cropping and management history.

5. Prior to normal land preparation when the soil is dry to slightly moist, use a subsoiler or "paraplow" to loosen the subsoil in the treated plot only. The depth of penetration should be approximately 10 cm deeper than the lower limit of the dense root-restricting layer, and the spacing of the subsoiler shanks should equal the depth of subsoiling for narrow-spaced crops, and correspond to, and coincide with, the row spacing for row crops.

6. Prepare the land for the whole field using normal farmer practice, and avoid excessive tractor passes as this may cause compaction and offset the benefits of subsoiling; greater benefits are likely to be obtained from conservation or reduced tillage for land preparation.

7. Sow the whole field with the agreed crop, and apply the same fertilisation, manuring, weed control, pest and disease management practices to both treated and control plots.

Monitoring:

8. Visit the site at 2-4 week intervals during the period of crop growth and monitor the following soil and crop indicators:

⇨ the appearance of the crop (degree of wilting during dry periods, height, vigour),

⇨ depth of rooting (determine at flowering and during pronounced dry periods),

⇨ soil moisture within and below the rooting zone (determine at flowering and during pronounced dry periods). Sampling depths must be the same for both treated and control plots.

Note: To observe the depth of rooting, dig three small 50 cm-deep pits of 1 meter length, parallel and close to the crop rows in both the treated and control plots. Compare the depths of rooting and soil moisture contents above and below the root-restricting layer in the plots.

Evaluation:

9. Harvest the two areas separately, and record the yields.

10. Calculate the gross margins for the two plots.

11. Evaluate the deep tillage treatment by comparing the depth of rooting, soil moisture contents during dry periods, yield and profit (gross margin) with that of the control plot.

Discussion: Initiate a discussion on the benefits (e.g. increased yields, greater profit ?), disadvantages (e.g. time required for subsoiling, heavy machinery becoming stuck in clayey soils after heavy rains), and feasibility of deep tillage (availability of tractor and subsoiler at appropriate times and when soil moisture is optimum).

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[6] Adapted from the "**Main Guidelines**", Trial 4, page 71.

Example 3. Raised beds to reduce waterlogging, increase oxygen supply to roots, and increase yields.

This example[7] applies to a manual tillage system, and differs from the first two examples in that the aim is to identify the optimum height of the beds, rather than to test the use of beds compared to flat cultivation.

Material required: Implements and supplies for land preparation, construction of raised beds, sowing, harvesting, manuring, fertilisation, weed, pest and disease control, stakes, spring balance, notebook.

A similar test could be carried out using tractor-powered or animal traction tillage systems, and modifying the dimensions of the beds and the plots.

Procedure:

1. Select a field with a poorly drained soil which is representative of the poorly drained soils of the area in terms of soil type, severity of waterlogging, cropping and management history, and where raised beds are, or could be, constructed.

2. Prepare the land in the conventional manner, and decide which crop is most suitable.

3. Mark out two plots, A and B, of at least 3 m x 2 m in size. Precise dimensions of the plots will depend on the aerial dimensions of the raised beds, which in turn will depend on the crop, crop spacing and soil type.

4. Construct raised beds of the same width separated by graded furrows in each of the two plots, but with the height of the beds above the soil surface at 30 cm in plot A and 15 cm in plot B. The specific values of the bed heights should be chosen after discussions with the farmers. Record the time taken to construct the two types of raised bed.

5. Sow the two plots at the same time, and apply the same fertilisation, manuring, weed, pest and disease control practices to all the plots.

Monitoring:

6. Observe the performance of the crop, the degree of waterlogging, and the crop's root development by digging a soil pit parallel to the middle row of the middle raised bed in each of the two plots. Monitor the following indicators at 2-4 weekly intervals:

⇨ depth to the water table from the top of the raised bed,

⇨ the zone of maximum rooting,

⇨ maximum depth of rooting,

⇨ crop vigour.

Evaluation:

7. Harvest the two plots separately and record the yields.

8. Calculate the gross margins for each plot.

9. Evaluate the influence of the height of the raised beds on the depth to the water-table, the development of roots, crop vigour, yield and cost of the labour.

Questions to facilitate discussion:

- Discuss the reasons for these differences, and the advantages (e.g. increased yields, greater profit ?), disadvantages (e.g. excessive labour needed for construction of higher beds), and feasibility of constructing raised beds (e.g. availability of labour).
- Extend the discussion to consider alternative methods (i.e. drainage) that could be used to create a deeper rooting zone free from waterlogging. Explain that specialised knowledge would be needed to select and design appropriate drainage systems. Discuss the advantages, disadvantages and feasibility of constructing raised beds, and of installing drainage ditches and diversion canals, and the suitability of these methods for different localities in the area.

[7] Adapted from the "**Main Guidelines**", Trial 71, page 74.

Tillage implements

The selection of the type of implement and the management of the tillage operations largely depend on the soil characteristics (structure and moisture). In fact, under inappropriate conditions, the implements may have the opposite effect and thus induce or increase soil problems (compaction, puddling, loss of structure and moisture, etc.).

Tillage implements may be manual, mechanical or powered by animal-traction. Some of them are only used in specific tillage systems, but others like disk harrows or cultivators may be appropriate for conventional and conservation tillage systems, providing they are used in a different way and/or are modified to suit to conservation practices.

Box 3. Comparison of different power sources used in tillage

Advantages of animal traction and tractor-powered tillage compared to manual tillage

- More rapid land preparation,
- Preparation of larger hectares,
- More timely planting,
- Increased revenue from hiring out animals or tractor,
- Improved efficiency in carrying loads using carts or trailers.

Advantages of animal traction compared to tractor-powered tillage

- Provision of manure to improve soil fertility,
- Lower investment costs for animals and implements,
- Lower level of skills for its utilisation,
- Provision of milk, meat and offspring.

Hand and animal traction tools

- Hand tools for ***zero tillage*** range from a **simple stick** to punch holes for placing the seeds to **seeder-planter** which injects the see and sometimes the fertiliser. Animal traction **seed planters** are also used for row crops and work with openers which consist of discs or star wheels; these can be coupled with fertiliser hoppers.
- **Cultivators** can be used for ***conservation tillage*** practices, to scarify the soil surface and thus control weeds and improve water infiltration while conserving soil covered by residues. **Tined cultivator** may be used for ***tine tillage*** with standard points, or with ducksfoot points in light textured soils, providing the residue cover is not high.
- **Ridgers** are use in animal traction systems for ***ridge tillage*** (**Fig. 4**), and can be coupled to seed-drills and even fertiliser applicator for a ***conservation tillage*** system (ridge tillage-seeding).
- **Disc harrows** and **chisels** (see “Mechanised implements” below) are implements also available for animal traction systems.

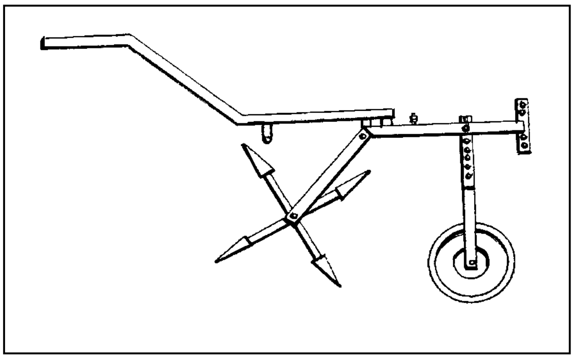

Figure 4: Implement for making tied-ridges with a single animal

- In ***conventional tillage*** systems using animal traction, *primary tillage* is carried out using a **mouldboard plough** (**Fig. 5**) or a traditional **wedge-shaped plough** that inverts the soil less than the mouldboard. On light textured soils, a **cultivator** with duckfoot or standard points may be used.
- Then, for *secondary tillage*, various passes of a **tine cultivator**, but with duckfoot points or sweeps, or rigid or flexible spike-toothed harrows may be used.

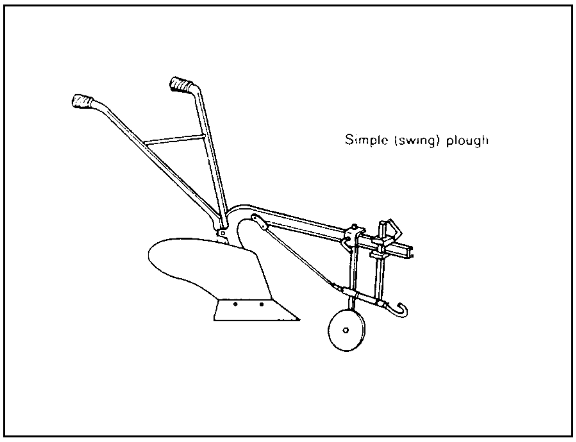

Figure 5. A simple mouldboard plough for animal traction tillage

- Due to the high labour demand, ***subsoiling*** is not applicable to manual nor animal traction systems.

Mechanised implements

- Mechanised **no-till** and **seed-drills planters** (**Fig. 6**) used in ***zero tillage*** systems are available for reseeding pasture, for sowing cereals and row crops. They are characterised by **spring-mounted coulters** in front of the furrow-opener to cut the residues, and usually with **double disc furrow-openers** for basal fertiliser placement and press wheels. These can be obtained by modifying conventional drills or planters. Depending on soil conditions, they work with **chisels**, **disks** or **star wheels**. The arrangement and the distance between the openers are calculated to avoid clogging due to the stubble.

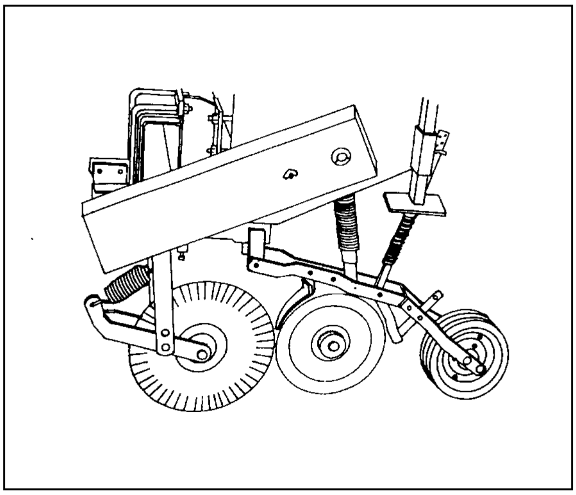

Figure 6. No-till drill seeding unit with rippled coulter, double disc furrow-opener and press wheel

- **Chisel plough** or **cultivator** are used for both ***conventional*** (in *secondary tillage* interventions) ***and reduced tillage*** (two passes followed by seeding), or even ***conservation tillage***, providing sufficient residues are left on the soil and the implements are equipped with front-mounted coulters. The tine spacing will influence the working depth, the number of passes needed and the power requirement of the tractor. Nevertheless, conditions of application should be carefully addressed, as for example the soil's texture and moisture content (dry to slightly moist), so that clods are broken and weeds controlled with minimised compaction risks.
- **Rotary cultivator / rotavator** may be used for ***reduced tillage*** purposes (one or two passes followed by seeding), but the negative features of this implement greatly outweigh the positive features, especially due to the **high degree of soil pulverisation**, and so its adoption should be restricted to structurally stable soils that are not notably susceptible to

crusting, compaction or erosion, and if no other solution is applicable.

- **Disc harrows** are used for both ***conventional*** as *secondary tillage* (two-three passes alone or followed by a cultivator) ***and reduced tillage*** (one or two passes followed by seeding). They incorporate most of the crop residues, though the amount of residues remaining on the surface will depend on the number of passes, and the angle of the discs. The greater the disc angle, the greater the degree of soil disturbance, and the greater the incorporation of residues. The sparse cover of crop residues that remain on the soil surface in this system would normally preclude it from being classified as conservation tillage.

  Disc harrow should only be used when for soils that are not notably susceptible to crusting, erosion or compaction, and where weeds can be effectively and economically controlled with herbicides.

- **Mouldboard plough** is often used for primary tillage in ***conventional tillage*** systems. A reversible mouldboard plough increases working efficiency. Alternatively, a single pass of a **disc plough** may be used which turns the furrow slice without inverting it.

- The **vibro-cultivator** is generally used for the *secondary tillage* in ***conventional and tine tillage*** systems. It has flexible and vibrating spring tines, spaced at about 10 cm to 15 cm, depending on the amount of residues left on the soil. Working depth should be 8-10 cm and tractor speed should be 8-12 km/h to optimise vibrations to uproot and shake weeds, and break up clods. One or two passes are recommended, the number depending on the degree of weed control and aggregate size required.

- Usual implements used for ***subsoiling*** are **rippers, subsoilers** (**Picture 6**, annex 2), or **paraplows -** also known as slant tine rippers.

  Paraplows differ from subsoilers in possessing heavy tines that are angled at right angles to the direction of work; this greatly diminishes the amount of large subsoil aggregates brought to the surface, reduces draft requirement and improves soil shattering. Subsoiling implements are normally used at greater depths than chisel ploughs:

Chisels:	10-25 cm
Rippers:	20-35 cm
Subsoilers, paraplows:	35-45 cm

  In ***conservation tillage*** systems, rippers are spaced at the row spacing and combined with fertiliser hoppers ("**Deep tillage-seeding**").

- **Miscellaneous**

  To reduce aggregates in moderately heavy and heavy soils a **crumbler roll** may be used. Further reductions in aggregate size and surface levelling can be obtained by coupling a **spike-toothed harrow, chain harrow, long-fingered rake, or levelling boards**.

  Crop residues can be shopped and spread during or after the harvest, using a rotary mower, straw chopper (**Picture 7**, annex 2), or by manual slashing.

  For ***horticultural crops*** that require fine seedbeds, **powered rotary cultivators or powered harrows** are often used. For light textured soils cultivators and spike-toothed harrows may be used to reduce aggregate size instead of disc harrows, and light rolls to firm very loose seedbeds. Levelling boards, blades or wooden planks are not recommended for light textured soils to avoid pulverisation. Rolls are used to break down large aggregates, such as a cage roll with angled bars for medium textured soils, and a heavy crumbler roll for heavy textured soils. For many crops a pre-sowing herbicide is applied and incorporated during the last pass of the disc harrow, cultivator or spike-toothed harrow.

Annex 1: Other tillage systems

The other tillage systems mentioned or described below are:

- **Mulch tillage** (a variation of Zero tillage)
- **Tine tillage** (also known as *vertical tillage*)
- **Strip tillage** (also known as *zonage tillage*)
- **Ridge tillage** (most built structures are part of Soil and Water Conservation techniques; see corresponding module)

Mulch tillage

In situations where it is difficult to provide an adequate cover of residues on the soil surface, a cover crop or planted fallow is sometimes sown either prior to starting zero tillage or as part of the rotation. Alternatively, land may be put down to natural fallow before initiating zero tillage.

The cover crop or fallow is usually killed with herbicides, or by manual slashing, and the following crop is seeded into the mulch, known as "*sod seeding*." Cover crops can also be eliminated by flattening and cutting with a roller-chopper (**Picture 8**, annex 2), which can be equipped with a sprayer to apply a systemic herbicide for simultaneous weed control.

All of the cover crop may be killed, or merely strips where the seed is to be placed. If the following crop is seeded into an untreated cover crop, or the cover crop has been only partially suppressed by slashing or using a roller-chopper, it is referred to as "*live mulch*".

Tine tillage

Also known as *vertical tillage*, tine tillage refers to tillage systems that use tined implements to loosen the soil without inverting it. In contrast to conventional systems, tine tillage causes minimal soil compaction. The whole soil surface is disturbed unlike in strip tillage, but the lack of inversion permits a proportion of the crop residues to be retained on the surface, giving a cover that is usually in excess of 30 %.

Tine tillage gives best results in fertile soils that are not compacted, are well drained, levelled and without serious weed problems. Any serious problem, infestation or deficiency should be fixed before tine tillage application. It is also advisable to begin with crops that permit good weed control, such as wheat, soybean or sunflower.

If the soil moisture is too high and the soil is plastic, fissures will be produced without breaking the clods or controlling weeds. If the soil is too dry, the clods may be very resistant to disintegration.

Tine tillage is most suited to the following situations:

- For mechanised farmers who can acquire the specialised tillage implements (i.e. stubble mulch chisel ploughs and cultivators), or who can modify their existing tined implements.
- For animal traction farmers provided the residue cover is low.
- For hardsetting and compaction-susceptible soils.
- For soils with moderate drainage problems but lacking severe weed problems.

The first tillage consists in breaking the aggregates and allow water infiltration while the second one should prepare the seedbeds, breaking up the biggest clods, uprooting weeds, levelling the surface and incorporating pre-seeding herbicides.

For tractor-powered systems a stubble mulch chisel plough is generally used, which is a chisel plough equipped with a front-mounted gang of disc coulters or individual disc coulters in front of each tine to cut the residues. For light textured soils a stubble mulch cultivator can be used.

Conventional planters and drills equipped with fertiliser hoppers can often be used for planting and basal application, unless the quantity of surface residues at seeding is high, when no-till drills and planters will be needed. Post-emergent weed control relies on herbicide application, preferably with sprayers.

Strip tillage / strip cropping

Strip tillage (**Fig. 7**), also known as *zonal tillage* refers to a system where 5 to 20 cm wide soil strips are prepared as a seedbed, whilst the soil in the intervening strips is left undisturbed and remains covered with residues to reduce risks of erosion and enhance infiltration.

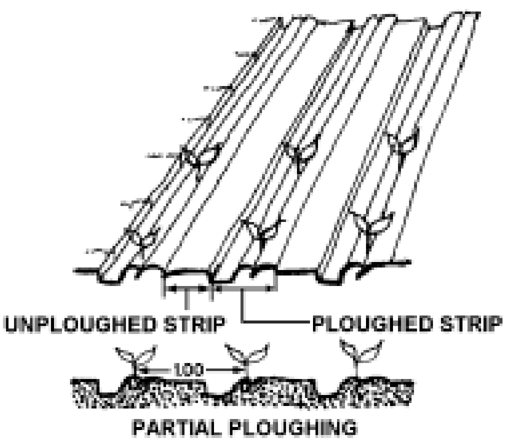

Figure 7: Strip ploughing system

Strip tillage is suited to the following conditions:

- Soils susceptible to compaction and hardsetting
- Soils that suffer from periodic drought
- Soils that give germination problems with zero tillage
- Soils that are not prone to severe crusting problems
- Where timeliness of sowing is important
- For **row crops**

In **animal traction and manual systems** the implements used for strip tillage are generally the same as used in conventional tillage, but only a fraction of the surface is tilled.

For **tractor-powered systems** it is difficult to modify conventional disc implements, and so tine tillage is used. The tined implements must be modified by removing some of the tines so that only strips of land 5-20 cm wide are tilled to 5-10 cm depth where the crop is to be seeded. The spacing of the tines will correspond to the inter-row spacing of the crop. The use of conventional chisel ploughs and cultivators would inevitably lead to clogging problems from the residues, and the positive conservationist features of strip tillage will be largely lost.

Weeds and crop residue management are similar to those use in zero tillage systems (see corresponding chapter). The land between the cultivated strips remains undisturbed and covered with residues to encourage rainfall infiltration and minimise erosion, but must be carefully managed to ensure that no weed, pest or disease problems develop that could spread to the crop in the tilled strips.

Conventional planters, preferably with fertiliser hoppers are used for both tractor-powered and animal-traction systems.

Ridge tillage

Ridge tillage is a generic term for a range of tillage practices that modify the soil surface by forming elevated or basin-like structures, with one or more of the following objectives:

to increase rainwater and soil conservation especially when there are insufficient quantities of crop residues for this purpose

or

to improve germination rates and crop growth by elevating the crop's rooting zone above a water table

or

to create loose soil conditions more suitable for root development and tuber formation

When ridge tillage is used to conserve rainwater and soil, the system falls within the broad definition of conservation tillage, but the formation of these structures causes major soil disturbance, and for many ridge tillage systems very little residue cover remains on the surface.

Some common forms of ridge tillage are presented below:

Ridges and furrows

Ridges and furrows are normally reformed every year. They can be used to conserve rainwater by constructing the furrows parallel to the contour, or to drain off excess water by making the furrows at an angle to the contour.

Tied ridges (**Fig. 8**) or basins is a variation of the ridge and furrow system in which cross-ties are constructed at intervals across the furrows. The cross ties retain rainwater by restricting lateral flow of the accumulated runoff and so allow longer time for infiltration, although evaporation losses will occur. By constructing the cross ties lower than the ridges, excess accumulated runoff can drain away. Nevertheless, on sloping land ridges, and especially tied ridges, are more prone to collapse when exceptionally heavy rainstorms cause unusually large amounts of rainwater to be retained, and saturation of the ridges weakens their stability. Collapse of the ridges can result in severe gully erosion.

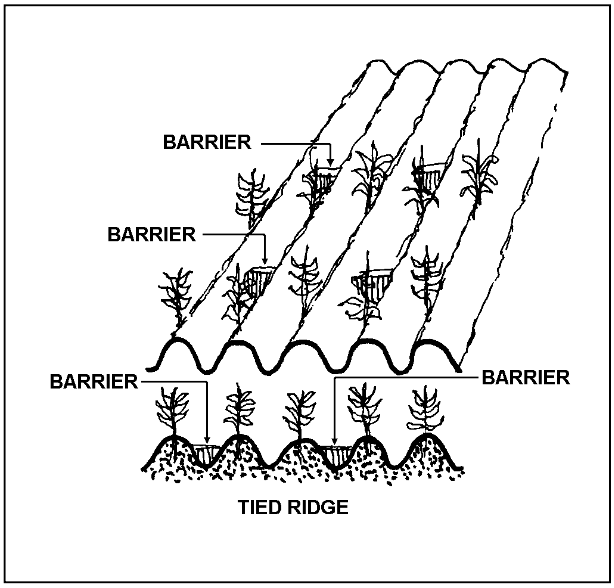

Figure 8: Tied-ridge system

Ridges and furrows can be made manually, by animal traction or by tractor. Mechanical construction usually involves primary tillage with a disc or chisel plough, followed by secondary tillage with a disc harrow or spring tined cultivator, and then a disc ridger, lister plough, or disc bedder to form the ridges. Construction of ridges by animal traction involves the use of a mouldboard plough, or a cultivator and ducksfoot points for lighter soils, followed by a ridger, which may be based on a mouldboard plough with two symmetrical mouldboards and an attached breastplate.

For tied ridges, the cross ties are usually a half to two thirds the height of the ridges, and spaced every 1-2 meters along the furrows. They are formed by scraping up soil from the bottom of the furrows with tie-makers made from disc or mouldboard plough shares in animal traction, or with tractor-mounted discs on eccentric cams, located behind the disc ridgers, which lift the tie-makers every 2 meters.

Ridges and furrows are most suited to the following situations:

- When insufficient crop residues are available for zero tillage
- For moisture-deficit and semi-arid areas with erratic rainfall
- For erosion-susceptible soils on land of **less than about 7% slope**
- For the production of tuber crops and groundnuts
- When sufficient labour is available (for manual tillage systems)

Raised beds

Raised beds are frequently made with the aim of either elevating the crop's germination and rooting zones above a high water table, and/or of loosening heavy textured soils to create better growing conditions for roots and, in particular, tuber crops. Raised beds (**Picture 2**, annex 2) are usually maintained for several years and are frequently used for horticultural crops. They may be formed manually, by animal traction or tractor, and are generally formed only on flat or very gently sloping lands. The height of the raised beds will depend on the depth of the crop's rooting zone that needs to be elevated above the water table. The width of the beds should generally be no wider than 10 meters in poorly drained soils to ensure good drainage.

Raised beds are most suited to the following situations:

- **Animal traction and manual tillage systems** (not suited to mechanised production systems)
- For poorly drained soils
- For medium to heavy textured soils on flat land where tuber crops are to be grown
- For horticultural crops
- Where sufficient labour is available for manual tillage

Mounds

Mounds (**Picture 3**, annex 2) are invariably **constructed by hand**, are usually reformed at the end of each cropping period (depending on the maturity period of the crop) when organic matter should be incorporated. The size of the mounds depends on whether the aim is to elevate the crop's rooting zone above a high water table, or to loosen a heavy textured soil to facilitate the growth of tubers.

Continual cultivation to the same depth over long periods may result in soil compaction and the formation of hoe-pans that restrict root penetration.

Mounds are most suited to the following situations:

- For **manual tillage systems**
- For poorly drained soils
- For medium to heavy textured soils on flat land where tuber crops are to be grown
- When sufficient manual labour is available

Cambered beds

Cambered beds are usually constructed mechanically in heavy textured soils with drainage problems, for semi-permanent crops such as sugar cane. The first operation is often deep tillage with a subsoiler to aid subsoil drainage.

The beds are formed by deliberate "up-hill" mouldboard ploughing towards the centre of the beds and are separated by drainage canals between the beds. Thus, the surface slope (camber) across the width of the bed encourages runoff and topsoil drainage. Drainage canals should be incised into the subsoil to a depth of some 40-50 cm so that water levels at normal flow remain below the topsoil.

Cambered beds are most suited to the following situations:

- For **mechanised production systems**, especially semi-permanent crops
- For poorly drained soils
- Where there is an adequate drainage system

Annex 2: Pictures

1. Zero tillage - wheat sown into soya residues using tractor-powered tillage, Saavedra, Bolivia

2. Raised beds - for horticultural crops, Honduras

3. Mounds - with sweet potatoes, Tororo District, Uganda

4. Conventional tillage - mouldboard ploughing with animal traction, Tororo District, Uganda


5. Rotating spike for manual planting, developed in Costa Rica


6. Subsoiler for deep tillage


7. Straw chopper for crop residues


8. Roller-chopper for cover crops and crop residues

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